RELATIONSHIPS BETWEEN ROCKWELL AND BRINELL NUMBERS[1]

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ABSTRACT

Comparative Rockwell and Brinell tests were made on a great variety of ferrous and nonferrous metals.

Relationships between Brinell and Rockwell numbers, based on certain simplifying assumptions, are:

$$\text{Brinell number} = \frac{\text{constant}}{130 - \text{Rockwell ball number}}$$

and

$$\text{Brinell number} = \frac{\text{constant}}{(100 - \text{Rockwell cone number})^2}$$

These equations were used as guides in finding empirical formulas which fitted most closely the values determined experimentally. Of all the experimental values obtained in this investigation very few differed by more than 10 per cent from values obtained from these empirical equations.

Empirical equations were also found giving the tensile strengths of steels in terms of their Rockwell numbers. Experimental values checked these equations within an error of plus or minus 15 per cent.

CONTENTS

I. INTRODUCTION

Indentation hardness tests are growing in importance as a means of checking the uniformity of the mechanical properties of metals used in engineering structures and machines.

If a metal is of uniform composition and the process of its manufacture is reasonably well controlled, uniform indentation numbers are nearly always a sufficient guarantee of its uniform quality. It is also found that the tensile strength of steel can be estimated from its Brinell number with sufficient accuracy for many commercial purposes.

The indentation test is preferred to a tensile test for control purposes because it is nondestructive and relatively inexpensive and because

[1] This paper supersedes a paper (B. S. Tech. Paper No. 334) with the same title and by the same author, published in 1927. The present paper includes the data (Tables 2 and 3) of the earlier paper, and, in addition, the results of many more tests on various heat-treated steels (Table 2 (*a*)).

it can be applied to pieces of the regular factory output. Since an indentation very seldom impairs the usefulness of a tested piece, it is in many cases not only possible but also practicable to test every piece produced.

Brinell and Rockwell hardness tests are two of the various indentation tests which are being widely used for control purposes, and situations often arise in which a Brinell (or Rockwell) number is needed when only a Rockwell (or Brinell) number can be obtained. In such cases a reliable chart or formula expressing a definite relationship between Rockwell and Brinell numbers is of great practical value.

II. PURPOSE OF INVESTIGATION

The purpose of this investigation was:

1. To make tests on a great number of the metals used in engineering construction and thus obtain data sufficient for determining the relation between Rockwell and Brinell numbers and also the relation between Rockwell numbers and tensile strength.
2. To determine the limits of error within which one of these numbers may be used to estimate the other number and the tensile strength of the material.

III. ACKNOWLEDGMENTS

The materials used in this investigation were contributed by the following manufacturers: Aluminum Co. of America, American Magnesium Corporation, Raritan Copper Works, Chase Metal Works, American Brass Co., Riverside Metal Works, International Nickel Co., Union Drawn Steel Co., Colonial Steel Co., American Rolling Mills Co., Central Alloy Steel Co., Halcomb Steel Co., Firth Sterling Steel Co., Carpenter Steel Co., and Wilson-Maeulen Co.

The metallurgical division of this bureau contributed data on Rockwell and Brinell numbers and tensile strengths for a great variety of steels.[2] (See Table 5.) These data made it possible to get a more conclusive check on the errors involved in the use of the conversion formulas.

Credit is due Dr. L. B. Tuckerman[3] for his many valuable suggestions. Prof. G. F. Rouse made the study of the diamond tool and edited the manuscript.

IV. APPARATUS AND PROCEDURE

The Brinell machine used in this investigation (see fig. 1) is provided with a dead-weight relief valve for maintaining the desired load on the indenting tool. This consists of a spherical piston accurately fitted, without packing, to a cylinder connected with the pressure chamber. This piston carries a crossbar, *A*, and weights, *B*. The maximum pressure is determined by the weights which are lifted by

[2] See Report in Trans. of A. S. M. E., 48, p. 533; 1926; entitled "Rough Turning With Particular Reference to the Steel Cut," by H. J. French and T. G. Digges. The Rockwell and Brinell numbers for hard steels were obtained on samples (Table 5, samples I-9D to I-16B) used by Dr. Gillett, chief, metallurgical division, Bureau of Standards, in his work on molybdenum and cerium steels. The composition, heat treatment, and other data for these steels will be found in the book, Molybdenum, Cerium, and Related Alloy Steels, by H. W. Gillett and E. L. Mack; 1925.

[3] Principal scientist, mechanics and sound division, Bureau of Standards.

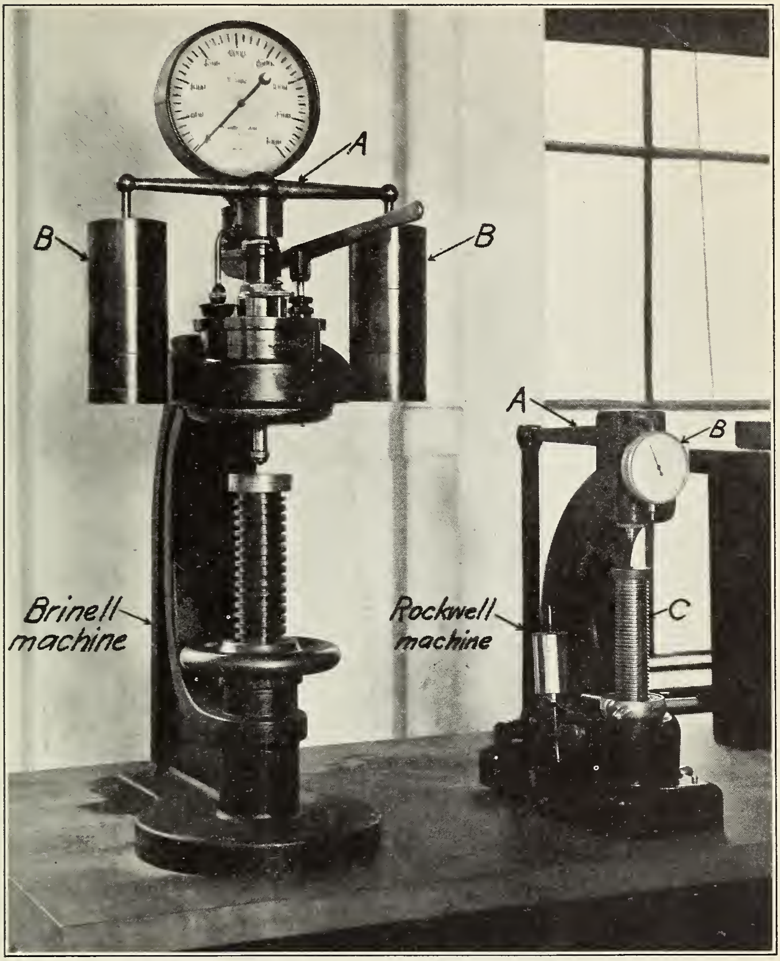

FIGURE 1.—*Brinell and Rockwell machines*

the piston as soon as this pressure is reached. The load remains constant as long as the piston floats.

A standard load of 3,000 kg was used in this investigation on metals having a Brinell number equal to or greater than 70, and a load of 500 kg was used on metals with a Brinell number less than 70. In every case the load was applied for 30 seconds. A Hultgren work-hardened steel ball, 10 mm in diameter, was used as the indenting tool.

The diameter of each indentation was measured with a Brinell microscope having 0.1 mm graduations. Readings were estimated to 0.01 mm.

The Brinell number was obtained directly from a table[4] which gives Brinell numbers corresponding to diameters of indentation.

The Rockwell machine shown in Figure 1 has a dead-weight loading device consisting of a double lever, *A*, having a total multiplication ratio of about 119. Materials listed in Table 2 were tested in this machine. A newer model having only one lever was used for testing the steels listed in Table 3. This machine was checked on the standard blocks used for the older model and all readings fell within limits of plus or minus 5 per cent of depth of indentation.

The specimen was placed on the table of the elevating screw, *C* (fig. 1), and was pressed against the indenting tool until a so-called minor load of 10 kg was acting. Next, the pointer on the indicating dial *B* was set at zero, after which the load was gradually increased to a maximum value, designated the major load. The load was then reduced to 10 kg and the Rockwell number was read from the dial.

The manufacturer recommends the following tools and loads for the Rockwell machine: A steel ball 1/16 inch (1.588 mm) in diameter with a 100 kg major load, on soft and medium materials; a steel ball 1/8 inch (3.176 mm) in diameter with a 100 kg major load, on very soft materials; and a diamond tool with a 150 kg major load on hard materials. This diamond tool, commonly called a cone, has an included angle of 120° and an apex lapped to a spherical surface. The tool is patented by the manufacturer, and has the trade name "brale." Other major loads of 100 kg and 60 kg were used with the brale and 60 kg with the 1/16-inch ball in order to obtain more complete data on the change of Rockwell numbers with change of load or indenting tool.

The direct reading dial *B* is provided with so-called "B" and "C" scales. The Rockwell ball number, designated in this paper by R_B, is read directly from the "B" scale. The cone number, designated in this paper by R_C, is read directly from the "C" scale. The calibration of the scales is such that the depth of indentation in mm, in excess of that produced by the minor load, is $(130-R_B)\times 0.002$ for the ball and $(100-R_C)\times 0.002$ for the cone.

There is no recognized standard for time under load in Rockwell testing. In this investigation the major load was removed approximately three-fourths second after it reached its maximum value.

Tests were made on six specimens to determine the change occurring in a Rockwell number due to a variation of time under load. The results are shown graphically in Figure 2. The greatest variation in average Rockwell number over a 10-second period, a decrease of 0.8

[4] Miscellaneous Publication of the Bureau of Standards, No. 62.

point, was found in the case of steel block C 24–25. The average decrease in Rockwell number, 0.3 of a point, is less than the difference usually found between individual readings on the same specimen.

V. THEORETICAL CONSIDERATIONS

Some symbols used in this discussion are:

Symbol	Meaning
Bn	Brinell number.
$_nR_{Bm}$	Rockwell ball number, obtained using a major load of n kg and a ball with a diameter of m inches.
$_kR_C$	Rockwell cone number, obtained using a major load of k kg and the brale.

Dr. J. A. Brinell, a Swedish engineer,[5] defined the indentation number which now bears his name as the ratio $\frac{P}{A}$, P being the load on

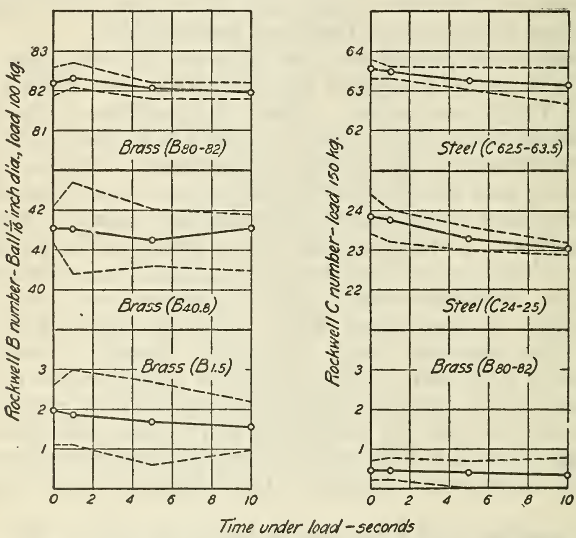

FIGURE 2.—*Effect of time under load upon Rockwell number*

Circles represent average values obtained from five indentations. Dash lines show extreme variations. Values for zero time were obtained within one-half second of the instant the major load reached its maximum value. Identification marks on the standard blocks are given in parentheses.

the indenting tool in kilograms and A the surface area of the indentation in square millimeters.

The Rockwell indentation number is defined as a constant minus the depth of indentation. The constant and the depth are expressed in arbitrarily selected units.

Investigation has shown that the Brinell number, as defined above, is not a constant of the test material; that is, that the area of an indentation is not directly proportional to the load. Many of the

[5] Congrès International des Méthodes d'Essai des Materiaux de Construction, 2, p. 83; 1901.

causes for this lack of proportionality can be given in a general way, but an exact theoretical discussion which involves the ratio $\frac{P}{A}$ and which takes into account all disturbing factors can not be given.

When it is impossible to carry out an exact deduction of a formula relating to quantities, one may resort to experiment and establish a purely empirical formula. Unfortunately, unless there is a great mass of well-distributed data, the purely empirical formula is, at best, often unsatisfactory. Whenever it is possible to make assumptions which are approximately true and which simplify the problem so that an approximate formula can be derived, there is an obvious advantage in carrying out the derivation because the resulting approximate formula is a valuable guide in finding the most satisfactory empirical formula.

In the present problem the simplifying assumption is Brinell's original assumption that the area of an indentation is always directly proportional to the load. Using this, it is possible to derive approximate formulas for converting Rockwell numbers into Brinell numbers or vice versa.

Applying the definition of the Brinell number to the Rockwell ball test:

$$Bn = \frac{\text{major load}}{\text{surface area of indentation}} = \frac{P}{2\pi r H} \qquad (1)$$

where P is the major load, r the radius of the indenting ball, and H the total depth of indentation. Let the depth of indentation due to the minor load only be denoted by h_0 and let $h = (H - h_0)$. Then, assuming that the area of indentation is directly proportional to the load,

$$\frac{H}{h_0} = \frac{P}{10} \text{ or } H = h_0 \cdot \frac{P}{10}$$

$$\therefore \qquad H = (H - h) \cdot \frac{P}{10}$$

$$H = h \cdot \frac{P}{P-10}$$

But $h = (130 - R_B) \times 0.002$

$$\therefore \qquad H = (130 - R_B) \times 0.002 \times \frac{P}{P-10}$$

Substituting in equation (1)

$$Bn = \frac{P-10}{2\pi r (130 - R_B) \times 0.002} \qquad (2)$$

Equation (2) can be written:

$$Bn = \frac{C}{(130 - R_B)} \qquad (3)$$

where

$$C = \frac{P-10}{2\pi r \cdot (0.002)} \qquad (4)$$

The value of C corresponding to any particular Rockwell ball test is easily found. For instance, considering the ${}_{100}R_{B1/16}$ case, in which a ball $\frac{1}{16}$ inch in diameter is used with a major load of 100 kg

$$C=\frac{90}{2\pi\cdot(0.794)\cdot 0.002}=9{,}020$$

$$\therefore \qquad Bn=\frac{9{,}020}{130-{}_{100}R_{B1/16}}$$

Values of C corresponding to the other Rockwell ball tests have been calculated, and all equations are shown in Table 1.

Assuming that the brale is a true cone and applying the definition of the Brinell number to it:

$$Bn=\frac{\text{major load}}{\text{surface area of indentation}}=\frac{P}{\pi \tan\theta \sec\theta H^2}$$

where P is major load, H the total depth of indentation, and θ one-half the angle of the cone.

TABLE 1.—*Approximate relationships between Brinell and Rockwell numbers based on the assumption that area of indentation is directly proportional to load*

Rockwell		Theoretical relationship
Tool	Load	
	kg	
Ball, 1/16 inch (1.588 mm) diameter	100	$Bn=\frac{9{,}020}{130-{}_{100}R_{B1/16}}$.
Ball, 1/8 inch (3.176 mm) diameter	100	$Bn=\frac{4{,}510}{130-{}_{100}R_{B1/8}}$.
Ball, 1/16 inch (1.588 mm) diameter	60	$Bn=\frac{5{,}010}{130-{}_{60}R_{B1/16}}$.
Brale, diamond, true cone having a 120° angle.	150	$Bn=\frac{1{,}896{,}000}{(100-{}_{150}R)^2C}$.
Do	100	$Bn=\frac{1{,}074{,}000}{(100-{}_{100}R_C)^2}$.
Do	60	$Bn=\frac{483{,}000}{(100-{}_{60}R_C)^2}$.
Brale, diamond, the apex being a spherical segment of altitude S, angle of conical portion 120°. (See fig. 3.)	150	Case I . . . For ${}_{150}R_C$ greater than $(100-466.7\,S)$. $Bn=\frac{1{,}492.9}{S(100-{}_{150}R_C)}$. Case II . . . For ${}_{150}R_C$ greater than $(100-2{,}953\,S)$ and less than $(100-466.7\,S)$. $Bn=\frac{150}{46.89S^2+10.882\,(L^2+4.308SL)}$. L is obtained in terms of ${}_{150}R_C$ and S from: $L^2+(4.308S)L+4.308S\,(S-15h_0)=0$ and $(100-{}_{150}R_C)\times 0.002=L+S-h_0$. Case III . . . For ${}_{150}R_C$ less than $(100-2{,}953\,S)$. $Bn=\frac{150}{46.89\,S^2+10.882(L^2+4.308SL)}$. L is obtained in terms of ${}_{150}R_C$ and S from $L^2+(4.308S)L-[60.325S^2+15(d^2+4.308Sd)]=0$ and $(100-{}_{150}R_C)\times 0.002=L-d$.

$${}_{100}R_{B1/16}=2\times{}_{100}R_{B1/8}-130$$

$${}_{100}R_{B1/16}=1.800\times{}_{60}R_{B1/16}-104$$

$${}_{100}R_C=1.491\times{}_{60}R_C-49.1$$

For a 120° cone,

$$Bn = \frac{P}{\pi \cdot \tan 60° \cdot \sec 60° \cdot H^2} = \frac{P}{10.882 H^2} \qquad (5)$$

If we assume that, in this case also, the area of indentation is proportional to the load,

$$\frac{\text{Major area}}{\text{Minor area}} = \frac{H^2}{h_o^2} = \frac{(h+h_o)^2}{h_o^2} = \frac{P}{10} \qquad (6)$$

$$\frac{h+h_o}{h_o} = \sqrt{\frac{P}{10}}$$

$$h_o = \frac{h}{\sqrt{\frac{P}{10}} - 1}$$

and

$$H^2 = \frac{h^2}{\left\{\sqrt{\frac{P}{10}} - 1\right\}^2} \times \frac{P}{10}$$

Using this value of H^2 in equation (5)

$$Bn = \frac{P}{10.882 \times \frac{h^2}{\left\{\sqrt{\frac{P}{10}} - 1\right\}^2} \times \frac{P}{10}}$$

$$= \frac{10\left\{\sqrt{\frac{P}{10}} - 1\right\}^2}{10.882 h^2}$$

$$= \frac{(\sqrt{P} - \sqrt{10})^2}{10.882 h^2}$$

Now

$$h = (100 - R_C) \times 0.002$$

$$\therefore \qquad Bn = \frac{(\sqrt{P} - \sqrt{10})^2}{10.882\,(100 - R_C)^2 \cdot (0.002)^2}$$

This equation can be written:

$$Bn = \frac{C_1}{(100 - R_C)^2} \qquad (7)$$

where

$$C_1 = \frac{(\sqrt{P} - \sqrt{10})^2}{10.882 \times (0.002)^2} \qquad (8)$$

Considering the ${}_{150}R_C$ case, in which the major load is 150 kg,

$$C_1 = \frac{(\sqrt{150} - \sqrt{10})^2}{10.882 \times (0.002)^2}$$

$$= 1,896,000$$

and

$$Bn = \frac{1,896,000}{(100 - {}_{150}R_C)^2}$$

A list of equations for all of the cone tests is given in Table 1.

The diamond indenting tool furnished with the Rockwell machine by the manufacturer is not a true cone, as assumed in the discussion just given, because it has a rounded apex approximating in form a spherical segment. A theoretical discussion for this form of tool when used with a 150 kg major load will now be given. (Refer to fig. 3.)

Assume that the rounded portion of the brale is a segment of a sphere of radius r. Let h_0 represent the depth of indentation produced by the minor load of 10 kg and h_1 that due to the major load of 150 kg.

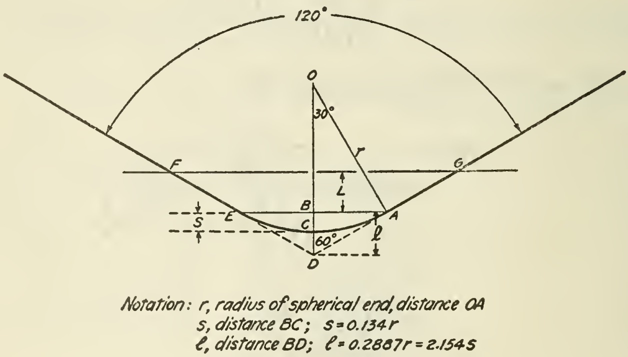

FIGURE 3.—*Form of Rockwell brale*

Three cases must be considered:

1. The major indentation is spherical; h_1 is less than S.

2. The minor indentation is spherical, while the major indentation is partly spherical and partly conical in form; h_0 is less than S, while h_1 is greater than S.

3. The minor, as well as the major indentation, is partly spherical and partly conical in form. Both h_0 and h_1 are greater than S.

It is assumed that the surface area of an indentation is directly proportional to the load producing it.

The area of a spherical segment having sagitta S and radius r is $2\pi rS$.

For a 120° cone the lateral area of a zone having a section $ABEFGA$ is 10.882 $(L^2 + 2lL)$, L being the vertical height of the zone.

Case I.—Since both the minor and major indentations are spherical an equation of the form $Bn = \frac{C}{100 - {}_{150}R_C}$ expresses the relation between Bn and ${}_{150}R_C$. (See equation (3), p. 23.)

For this particular case $C=\frac{140\times 0.134}{2\pi S\times 0.002}=\frac{1492.9}{S}$, and the relation is

$$Bn=\frac{1492.9}{S(100-{}_{150}R_C)} \tag{9}$$

This equation holds for values of ${}_{150}R_C$ greater than $(100-466.7S)$. This value of ${}_{150}R_C$ is obtained by combining the equations:

$$\frac{\text{depth of minor indentation}}{\text{depth of major indentation}}=\frac{h_0}{S}=\frac{10}{150}$$

and

$$(100-{}_{150}R_C)\times 0.002=S-h_0.$$

Case II.—By definition

$$Bn=\frac{150}{2\pi rS+10.882(L^2+2lL)} \tag{10}$$

where $L=h_1-S$.

Substituting values for r and l in terms of S, equation (10) becomes

$$Bn=\frac{150}{46.89S^2+10.882(L^2+4.308SL)} \tag{11}$$

In order to find a value for the variable L in terms of ${}_{150}R_C$ two other equations must be written. These are:

$$\frac{\text{Major area}}{\text{Minor area}}=\frac{2\pi rS+10.882(L^2+2lL)}{2\pi rh_0}=\frac{150}{10}$$

which reduces to:

$$L^2+(4.308S)L+4.308S(S-15h_0)=0 \tag{12}$$

and

$$(100-{}_{150}R_C)\times 0.002=L+S-h_0 \tag{13}$$

By eliminating h_0 from equations (12) and (13) a value of L is obtained which can in turn be substituted in equation (11) to get an expression containing Bn, ${}_{150}R_C$, and S. This expression would be complicated, and it seems simpler to use equations (11), (12), and (13) as they stand.

These equations hold for values of h_0 greater than 0.0666 S and less than S. The first limit is determined by the fact that the depth of the major indentation just equals S when the depth of the minor indentation, or $h_0=\frac{S}{15}$. The second limit is fixed by the definition of this case.

Case III.—

$$Bn=\frac{150}{2\pi rS+10.882(L^2+2lL)}$$

$$=\frac{150}{46.89S^2+10.882(L^2+4.308SL)} \tag{14}$$

The equations needed to solve for L are:

$$\frac{\text{Major area}}{\text{Minor area}}=\frac{2\pi rS+10.882(L^2+2lL)}{2\pi rS+10.882(d^2+2ld)}=\frac{150}{10}\text{ (where } d=h_0-S)$$

which reduce to:

$$L^2+(4.308S)L-\{60.325S^2+15(d^2+4.308Sd)\}=0 \tag{15}$$

and

$$(100-{}_{150}R_C)\times 0.002=L-d \tag{16}$$

Equations (14), (15), and (16) can be solved simultaneously to obtain an expression in Bn, ${}_{150}R_C$, and S. In this case it also seems much simpler to use the equations as they are given.

These equations hold for all positive values of d.

Values for ${}_{150}R_C$ and Bn in terms of S given in columns 4 and 5 of Table 6 were calculated by means of equations (9) to (16).

By equating values of Bn given in Table 1, relationships between the Rockwell numbers are obtained. For instance, using the first two values for Bn:

$$\frac{9{,}020}{(130-{}_{100}R_{B1/16})}=\frac{4{,}510}{(130-{}_{100}R_{B1/8})}$$

or

$${}_{100}R_{B1/16}=2\times{}_{100}R_{B1/8}-130$$

The more important equations obtainable in this way are given in Table 1.

Attention is again called to the fact that the formulas discussed above and listed in Table 1 are only approximately true. As will be shown later, empirical formulas, like these in general form, fit experimental data quite satisfactorily.

VI. EXPERIMENTAL DATA

The specimens used in this investigation are listed and described in Tables 2 and 3. Experimental Rockwell and Brinell numbers for specimens listed in Table 2 are found in Table 4. The Brinell and Rockwell numbers for the heat-treated steels are found in the right-hand columns of Table 3.

TABLE 2.—*Materials used for Brinell and Rockwell tests*

FERROUS MATERIALS

[Condition: As received from mill]

Sample No.	Material	C	Mn	Si	P	S	Ni	Cr	V	W	Yield [a] point	Tensile strength	Elongation in 2 inches
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Lbs./in.²*	*Lbs./in.²*	*Per cent*
1	Low-carbon steel	0.16	0.33	0.12	0.007	0.023					57,650	63,500	21.5
53	do	.09									37,550	51,400	41.3
54	Medium-carbon steel	.28									44,700	69,350	31.3
2	do	.31	.52	.26	.014	.033					79,350	91,350	16.5
55	High-carbon steel	.68									62,800	118,500	18.5
4	do	.85	.33	.16	.020	.010					81,900	96,200	23.3
28	Carbon-tool steel	.90											
5	Nickel steel	.35	.74	.12	.014	.022	3.42				96,950	117,450	15.5
27	3½ per cent nickel steel										120,650	198,750	11.5
6	Chromium steel	.91	.30	.36	.016	.014		1.43			88,600	96,300	26.5
57	do	1.01						1.33			108,600	191,250	5.8
7	Nickel-chromium steel	.32	.54	.10	.017	.018	2.88	1.27			79,000	95,550	21.3
56	do	.30					2.14	.82			85,800	131,600	19.0
58	Chromium-vanadium steel	.30						1.11	0.25		92,850	133,350	23.0
9	do	.35	.57	.20	.013	.016		.90	.17		81,950	94,400	24.0
8	Silicon steel	.59	.71	1.88							75,200	104,950	23.8
59	Tungsten steel	.60						3.50		14.00	57,050	115,400	18.5
SS	Stainless steel	.30	.30					13.00			69,000	103,000	25.5
BC	High-speed steel	.65						4.50	1.50	13.50	54,300	110,600	20.5
A	Cast iron	3.83	.72	1.51	.400	.072							
C	do	3.60	.42	1.76	.820	.052							
H	do	3.18	.46	2.66	1.85	.078							

[a] Determined as stress at which the deformation is 0.01 inch in 2 inches.

TABLE 2.—*Materials used for Brinell and Rockwell tests*—Continued

NONFERROUS MATERIALS

Sample No.	Material	C	Mn	Si	Ni	Al	Cu	Mg	Sn	Zn	Pb	Fe	Condition [b]	Yield point [c]	Tensile strength	Elongation in 2 inches
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Lbs. in.*[2]	*Lbs. in.*[2]	*Per cent*
10	SAE-Al-alloy No. 30		0.08	0.58		90.8	7.95			Nil.		0.59	Cast	12,700	16,400	1.5
11	Al-alloy, 2 S		.01	.35		99.0	.19					.44	Rolled	5,650	14,950	37.0
12	Duralumin		.60	.35		94.36	3.71	0.49				.49	do	38,150	58,300	16.0
13	Magnesium (2039)							99.9					Extruded, 300° C	19,000	28,650	11.3
14	Mg-alloy (2038)		.3			4.0		Balance.					Cast, sand, 685° C		8,900	2.5
15	Mg-alloy (2016-HT)		.3			4.0		Balance.					Rolled, h. t. at 450° C.; quenched in water.	21,550	35,400	16.8
16	Mg-alloy (2016-R)		.3			4.0		Balance.					Extruded, 290° C.; rolled 450° C.	28,200	37,850	16.1
17	Mg-alloy (2016-E)		.3			4.0		Balance.					Extruded, 290° C	29,700	40,000	17.5
20	Phosphor bronze (soft)		.05				89.35		10.23	Nil.	0.01	.04	Cold-rolled, annealed	26,500	61,550	77.3
21	Phosphor bronze (hard).		.05				89.35		10.23	Nil.	.01	.04	Cold-rolled	86,600	101,000	22.0
22	Nickel silver (soft)		.21		17.92		63.70			18.0	Nil.	.17	Cold-rolled, annealed	27,850	61,400	44.0
23	Nickel silver (hard)		.19		18.13		63.73			17.77	.015	.16	Cold-rolled	85,000	86,700	8.5
24	Brass (soft)						65.12			34.79	.08	.01	Cold-rolled, annealed	14,770	43,200	80.5
25	Brass (hard)						65.12			34.79	.08	.01	Cold-rolled	54,250	60,550	27.5
33	Monel metal	0.2	1.75	.1	66.0		30.0					2.0	Hot-rolled	34,800	86,650	48.8
34	Nickel	.1	.25	.1	99.0		.2					.5	do	33,950	84,850	48.0
35	Aluminum bronze (soft).					7.92	91.90			.18			Cold-rolled, annealed	14,200	61,800	74.3
36	Aluminum bronze (hard).					7.55	92.16			.29			Cold-rolled	33,000	63,900	66.0
37	Copper (soft)						99.97						Cold-rolled, annealed	8,550	30,600	54.0
38	Copper (hard)						99.97						Cold-rolled	34,000	35,650	31.5

[b] As reported by the manufacturer.

[c] Determined as stress at which the deformation is 0.015 inch in 2 inches.

TABLE 3.—*Heat-treated materials used for Brinell and Rockwell tests*

FERROUS MATERIALS

Sample No.	Material	Heat treatment			Chemical composition										*Bn*	$_{150}Rc$
		Quenching medium	Quenching temperature	Drawn	C	Mn	Si	P	S	Cr	Ni	V	W	Co		
			° *F.*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
D-15	Carbon steel	Brine	1,420	Not drawn	0.80	0.20	0.25	0.001	0.015	------	------	------	------	------	724	67.5
D-5	do	do	1,420	340° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	678	64.5
D-6	do	do	1,420	450° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	627	60.8
D-2	do	do	1,420	505° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	599	58.1
D-12	do	do	1,420	610° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	557	55.3
D-7	do	do	1,420	665° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	514	52.3
D-8	do	do	1,420	755° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	476	49.3
D-9	do	do	1,420	855° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	427	45.3
D-10	do	do	1,420	915° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	389	42.2
D-11	do	do	1,420	1,000° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	333	36.7
D-4	do	do	1,420	1,050° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	310	33.9
D-13	do	do	1,420	1,110° F., 60 min	.80	.20	.25	.001	.015	------	------	------	------	------	277	29.3
D-14	do	do	1,420	1,175° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	250	25.0
D-3	do	do	1,420	1,215° F., 30 min	.80	.20	.25	.001	.015	------	------	------	------	------	240	23.4
D-1	do	do	1,420	1,250° F., 60 min	.80	.20	.25	.001	.015	------	------	------	------	------	221	19.1
E-4	do	do	1,420	Not drawn	1.20	.20	.25	.001	.015	------	------	------	------	------	755	68.4
E-2	do	do	1,420	310° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	686	67.1
E-7	do	do	1,420	450° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	631	62.7
E-3	do	do	1,420	550° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	587	58.6
E-8	do	do	1,420	665° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	529	54.3
E-9	do	do	1,420	755° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	491	51.9
E-12	do	do	1,420	850° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	439	47.7
E-13	do	do	1,420	915° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	403	44.2
E-14	do	do	1,420	980° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	352	40.5
E-5	do	do	1,420	1,050° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	313	34.7
E-1	do	do	1,420	1,110° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	295	32.5
E-15	do	do	1,420	1,130° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	279	29.4
E-10	do	do	1,420	1,175° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	259	26.5
E-11	do	do	1,420	1,235° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	246	23.8
E-6	do	do	1,420	1,300° F., 30 min	1.20	.20	.25	.001	.015	------	------	------	------	------	224	19.9

TABLE 3.—*Heat-treated materials used for Brinell and Rockwell tests*—Continued

FERROUS MATERIALS—Continued

Sample No.	Material	Heat treatment: Quenching medium	Heat treatment: Quenching temperature	Heat treatment: Drawn	Chemical composition: C	Mn	Si	P	S	Cr	Ni	V	W	Co	Bn	$_{150}Rc$
			° F.		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		
2B-1	3½ per cent nickel steel	Water	1,600	Not drawn	0.15	0.49		0.029	0.020		3.46				394	41.9
2B-4	do	do	1,600	950° F., 60 min	.15	.49		.029	.020		3.46				224	20.8
2B-5	do	do	1,600	1,250° F., 60 min	.15	.49		.029	.020		3.46				183	10.9
4B-1	do	do	1,500	Not drawn	.35	.76		.010	.020		3.44				516	53.0
4B-2	do	do	1,500	350° F., 60 min	.35	.76		.010	.020		3.44				488	47.9
4B-3	do	do	1,500	650° F., 60 min	.35	.76		.010	.020		3.44				387	39.9
4B-4	do	do	1,500	950° F., 60 min	.35	.76		.010	.020		3.44				285	30.4
4B-5	do	do	1,500	1,250° F., 60 min	.35	.76		.010	.020		3.44				212	17.5
1D-4	Chromium steel	Oil	1,500	950° F., 60 min	1.01	.22		.026	.024	1.33					345	37.3
1D-5	do	do	1,500	1,250° F., 60 min	1.01	.22		.026	.024	1.33					284	30.1
C-1	High chromium steel	do	1,750	Not drawn	2.20	.20	.30	.001	.015	12.0		0.80		0.50	748	68.0
C-3	do	do	1,750	310° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	703	65.2
C-5	do	do	1,750	550° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	628	60.9
C-9	do	do	1,750	915° F., 30 min 850° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	574	56.3
C-10	do	do	1,750	1,000° F., 30 min 980° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	538	54.3
C-6	do	do	1,750	1,050° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	506	51.9
C-11	do	do	1,750	Twice 1,130° F., 30 min. each	2.20	.20	.30	.001	.015	12.0		.80		.50	456	48.1
C-12	do	do	1,750	1,175° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	433	45.4
C-14	do	do	1,750	1,235° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	401	42.8
C-13	do	do	1,750	1,265° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	377	40.7
C-8	do	do	1,750	1,300° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	342	36.8
C-4	do	do	1,750	1,330° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	330	35.1
C-15	do	do	1,750	1,380° F., 30 min	2.20	.20	.30	.001	.015	12.0		.80		.50	301	32.1
C-2	do	do	1,750	1,440° F., 60 min	2.20	.20	.30	.001	.015	12.0		.80		.50	269	26.9
C-7	do	do	1,750	1,440° F., 3 hr., 15 min	2.20	.20	.30	.001	.015	12.0		.80		.50	247	24.1
6C-1	Chromium-nickel steel	do	1,550	Not drawn	.30	.70		.035	.027	.82	2.14				469	47.5
6C-2	do	do	1,550	350° F., 60 min	.30	.70		.035	.027	.82	2.14				472	48.0
6C-3	do	do	1,550	650° F., 60 min	.30	.70		.035	.027	.82	2.14				423	42.8
6C-4	do	do	1,550	950° F., 60 min	.30	.70		.035	.027	.82	2.14				321	34.2
6C-5	do	do	1,550	1,250° F., 60 min	.30	.70		.035	.027	.82	2.14				253	25.1

B-2	Chromium-vanadium steel.	Brine	1,475	Not drawn	.90	.20	.25	.001	.015	.80	----	.20	----	----	709	66.1
B-1	do	do	1,475	310° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	671	63.4
B-7	do	do	1,475	450° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	627	59.3
B-3	do	do	1,475	550° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	578	56.6
B-8	do	do	1,475	665° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	538	53.6
B-12	do	do	1,475	755° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	502	51.0
B-9	do	do	1,475	850° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	456	47.1
B-10	do	do	1,475	915° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	420	44.6
B-11	do	do	1,476	980° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	401	42.9
B-4	do	do	1,475	1,050° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	354	38.2
B-14	do	do	1,475	Twice, 1,110° F., 30 min. each	.90	.20	.25	.001	.015	.80	----	.20	----	----	325	34.7
B-13	do	do	1,475	1,175° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	290	31.0
B-15	do	do	1,475	1,215° F., 60 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	259	26.2
B-6	do	do	1,475	1,300° F., 30 min	.90	.20	.25	.001	.015	.80	----	.20	----	----	236	22.3
B-5	do	do	1,475	Twice, 1,330° F., 30 min. each	.90	.20	.25	.001	.015	.80	----	.20	----	----	224	20.4
A-5	High-speed steel	Oil	2,330	Not drawn	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	709	66.2
A-1	do	do	2,330	1,100° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	698	63.3
A-2	do	do	2,330	1,200° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	657	60.7
A-4	do	do	2,330	1,235° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	611	57.3
A-6	do	do	2,330	1,265° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	547	53.0
A-7	do	do	2,330	1,300° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	500	49.9
A-8	do	do	2,330	1,330° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	444	45.5
A-10	do	do	2,330	1,360° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	403	42.7
A-3	do	do	2,330	1,420° F., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	368	39.0
A-12	do	do	2,330	1,440° F., 1 hr., 15 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	340	35.7
A-9	do	do	2,330	1,480° F., 1 hr., 30 min	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	313	33.8
A-11	do	do	2,330	1,525° F., 30 min.; 6 hr., 20 min., cooling from 1,525° F. to 1,370° F.	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	304	32.0
A-13	do	do	2,330	1,600° F., 30 min.; 7 hr., cooling from 1,600° to 1,370° F.; 14 hr. at 1,370° F.; showed slight carbon absorption so 1/32 in. was machined off. Sample was then reheated to 1,460° and oil quenched.	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	256	23.7
A-14	do	do	1,650	1,410° F., 14 hr	.68	.20	.32	.001	.015	4.00	----	1.00	18.00	----	284	29.4

TABLE 4.—*Rockwell and Brinell indentation numbers for materials described in Table 2*

Sample No.	Bn	$_{100}R_{B1/16}$ [1]	$_{100}R_{B1/8}$ [2]	$_{60}R_{B1/16}$	$_{150}R_C$ [3]	$_{100}R_C$	$_{60}R_C$
I. FERROUS MATERIALS							
53	98	55.2	91.8	90.1	−24.0	8.0	42.8
54	125	68.2	99.1	96.8	−6.7	20.0	47.7
1	129	74.0	102.5	99.0	−5.0	23.5	------
A	156	79.0	------	------	------	------	------
28	178	85.3	106.2	105.0	7.5	33.3	55.0
C	192	91.0	------	------	------	------	------
9	204	92.6	112.0	109.5	16.5	39.0	------
2	204	94.9	112.8	111.4	18.4	40.7	------
7	212	93.8	112.5	110.2	18.6	40.2	------
H	216	94.0	------	------	------	------	------
6	224	96.4	113.1	111.7	20.0	40.1	------
55	225	98.4	113.2	112.0	19.7	42.4	62.2
SS	225	98.0	114.0	112.3	21.6	42.2	------
8	226	96.8	112.8	111.1	22.2	42.0	------
59	230	96.8	112.1	111.7	19.1	41.2	62.1
4	232	97.2	114.2	112.2	22.0	42.5	------
BC	239	98.0	112.6	111.9	21.2	42.0	------
5	248	97.6	113.5	112.5	22.5	42.1	------
56	256	102.3	116.2	114.6	27.7	46.0	64.6
58	268	104.6	117.1	116.2	28.4	48.1	65.8
57	339	108.0	118.8	117.4	36.8	52.1	68.5
27	367	111.6	121.4	120.2	41.9	56.8	71.9
II. NONFERROUS MATERIALS							
11	28.0	(4)	−3.0	−25.0	(4)	(4)	−18.0
37	42.0	−39.0	35.6	35.0	(4)	(4)	1.6
14	43.4	−40.0	42.0	39.0	(4)	(4)	(4)
13	43.5	(4)	46.0	34.0	(4)	(4)	5.0
15	50.3	−15.0	59.6	53.5	(4)	(4)	15.0
24	[5] 51.4	9.5	66.1	64.9	(4)	(4)	23.4
16	56.8	4.1	70.1	62.7	(4)	(4)	22.1
17	61.3	20.0	75.0	70.4	(4)	−12.0	25.5
10	67.7	25.0	81.0	77.0	[6] −35.0	0	[6] 35.0
35	72	36.5	76.7	76.0	(4)	−6.5	30.0
38	75	33.9	86.5	79.2	−35.0	0	36.0
20	95	51.1	86.8	85.0	−29.0	6.0	38.0
22	103	58.4	90.7	90.2	−21.0	12.3	41.6
36	111	65.2	93.9	93.1	−15.0	14.9	43.6
12	123	69.9	98.1	97.2	−8.8	19.3	48.1
25	126	72.8	102.1	99.0	−3.0	22.8	49.5
34	132	74.3	99.0	98.6	−6.1	21.8	48.2
33	147	78.5	101.9	100.5	1.0	27.1	52.5
23	174	88.8	110.7	108.1	13.1	36.3	57.6
21	218	98.3	114.3	112.4	21.8	42.0	62.4

[1] Standard Rockwell B number.
[2] Standard Rockwell E number.
[3] Standard Rockwell C number.
[4] Too soft.
[5] For 3,000 kg load Bn=65.
[6] About.

Table 5 contains data obtained in the metallurgical division of this bureau.

All tensile-strength data were obtained on A. S. T. M. standard specimens (0.500 inch diameter, 2-inch gage length).

All steel specimens were machined before an indentation was made. Certain tests made on nonferrous materials showed that results obtained on the rolled surfaces differed a negligible amount from those obtained on machined surfaces. Therefore in many of the tests on nonferrous materials indentations were made on the rolled surfaces of the specimens as received from the manufacturer.

The Rockwell indentations on each specimen were located between and near the Brinell indentations. Each experimental indentation number listed in the tables is the average obtained from at least four indentations.

The following study was made on each of five Rockwell brales. By means of a contour measuring projector giving a magnification of 234, a shadow of the brale was formed on a screen, the shadow being a projection of a cross section of the tool through its axis. The outline of the shadow was carefully traced. A second and a third tracing were obtained after the brale had been rotated 60° and 120°, respectively, about its axis.

TABLE 5.—*Data on steels furnished by metallurgical division, Bureau of Standards*

Sample No.	Brinell No.	$_{100}R_{B1/16}$	$_{150}R_C$	Experimental tensile strength
				Lbs./in.^{2}
16-3	125	71.4		68,500
16-4	128	70.1		69,200
29-2	131	77.7		70,000
29-1	134	75.7		69,500
8-R	156	83.1		82,500
2-F	157	83.4		84,500
2-CA	161	86.0		84,500
2-C	165	85.5		85,000
15-7	167	85.8		91,000
17-1	168	83.9		87,300
2-Q	169	86.9		86,500
34-1	169	87.4		77,500
7-2	170	84.5		87,300
8-FA	170	86.5		83,000
8-RA	170	87.2		86,000
15-1	170	87.5		92,500
15-8	173	85.0		91,000
8-F	173	86.7		84,500
3-FA	174	87.0		92,000
34-2	174	86.6		77,500
6-FA	175	89.7		91,000
6-F	180	89.7		91,500
1-FA	181	89.6		93,000
1-F	181	89.3		92,500
9-RA	184	88.9		92,500
3-F	187	89.2		92,000
9-FA	189	90.3		93,000
9-F	191	90.0		93,500
1-RA	192	91.7		96,000
3-RA	193	91.3		92,000
3-R	194	91.8		98,000
1-R	195	92.4		97,000
5-A	197	95.3	12.6	103,000
35-1	197	93.5		92,000
36-2	197	91.3		99,500
35-2	198	94.6		93,500
36-1	199	91.4		99,000
5-FA	204	92.6		102,000
5-F	207	92.9		103,500
6-RA	209	95.5		101,500
6-R	209	94.5		101,500
5′	215	98.7	16.8	102,500
9-R	223	97.1		100,000
25-A-1	226	100.0	20.2	113,500
7-FA	229	98.4	21.3	114,500
5-RA	229	97.5		116,000
5-R	229	96.8		115,000
25-A-2	229	99.5	21.1	115,500
19-1	229	95.0		107,600
19-2	229	95.0		107,000

TABLE 5.—*Data on steels furnished by metallurgical division, Bureau of Standards*—Continued

Sample No.	Brinell No.	$_{100}R_{B1/16}$	$_{150}R_C$	Experimental tensile strength
				Lbs./in.^{2}
14-RA	247	99.0	23.8	126,000
14-F	248	100.3	24.9	134,000
13-O-A	250	101.6	25.9	128,000
11-F	252	101.1	25.3	123,700
13-O	254	101.5	25.9	128,500
13-CA	255	100.4	26.0	126,000
13-C	255	101.1	25.8	127,500
32-1	255	101.3	23.3	123,000
12-FA	256	101.4	26.5	124,000
12-C	257	103.9	25.5	122,000
12-CA	257	102.9	25.7	122,500
12-F	260	101.5	27.0	125,000
32-2	262	101.2	23.3	123,500
33-1	262	101.9	24.8	126,500
33-2	262	102.4	26.2	126,000
11-R	265	103.0	26.8	128,500
10-A-2	265	100.4	27.2	119,000
11-RA	267	103.1	27.6	125,500
10-F	267	102.3	26.6	127,000
10-FA	269	102.8	27.6	128,500
7-RA	270	103.0	28.8	131,000
7-R	273	103.0	29.4	132,500
11-FA	273	102.8	27.7	130,500
10-R	285	104.7	30.0	139,000
11-A-4	288	101.9	27.7	134,000
10-RA	293	105.2	32.2	138,500
12-RA	297	105.9	31.0	139,500
28-4	300	107.1	31.1	142,500
12-R	300	105.9	32.8	139,000
26-1-A	302	106.4	33.5	145,700
14-A-2	304	106.1	34.5	150,000
11-A-1	305	104.3	29.3	134,000
14-A-1	306	105.9	34.4	150,500
15-A-2	311	104.6	32.0	149,700
12-A-2	317	105.9	33.6	148,000
12-A-1	321	106.3	33.5	149,500
15-A-1	321	105.2	32.5	147,000
30-A-8	330	110.1	32.9	149,600
10-A-1	334	110.8	34.4	147,500
20-2	341	113.4	33.2	167,200
20-1	363	112.8	36.4	186,400
20-4	363	113.9	35.0	170,600
25-2	363	112.7	36.4	167,000
20-3	375	114.4	36.2	181,500
25-1	388	115.0	41.2	189,700
27-A-6	388	114.5	39.8	190,000
27-A-3	395	115.0	40.5	200,500
I-9D	407	----------	41.9	192,200
I-32D	408	----------	42.4	192,200
I-28B	434	----------	43.6	205,200
I-8B	450	----------	45.9	214,700
I-32C	512	----------	50.5	248,500
I-9C	518	----------	50.0	250,000
I-28A	525	----------	51.0	258,200
I-30D	527	----------	51.1	273,700
I-10D	536	----------	52.2	268,700
I-16B	542	----------	51.7	283,000

TABLE 6.—*Table of values for diamond brale*

Case	h_0	d	L	Rockwell C number load 150 kg	Brinell number	For S=0.0224 mm: Bn	For S=0.0224 mm: $_{150}Rc$	For S=0.0224 mm: $\frac{1}{\sqrt{Bn}}$	For S=0.0291 mm: Bn	For S=0.0291 mm: $_{150}Rc$	For S=0.0291 mm: $\frac{1}{\sqrt{Bn}}$
Case I	h_0 varies from 0 to 0.0666S	-------	-------	Rockwell C number varies from (100–466.7 S) to 100	Brinell number varies from $\frac{3.199}{S^2}$ to ∞	∞	100	0	∞	100	0
						33,324	98	0.0055	25,651	98	0.0062
						16,662	96	.0077	12,826	96	.0088
						11,108	94	.0095	8,550	94	.0108
						8,331	92	.0110	6,413	92	.0125
						6,665	90	.0123	5,130	90	.0140
						6,378	89.5	.0125	3,778	86.4	.0163
Case II	0.07 S	-------	0.049 S	100– 489.5 S	3.048/S^2	6,075	89.0	.0128	3,599	85.8	.0167
	.10 S	-------	.453 S	100– 676.0 S	2.133/S^2	4,251	84.9	.0153	2,519	80.3	.0199
	.15 S	-------	1.012 S	100– 931.0 S	1.422/S^2	2,834	79.1	.0188	1,679	72.9	.0244
	.20 S	-------	1.487 S	100–1,143 S	1.066/S^2	2,125	74.4	.0217	1,259	66.7	.0282
	.30 S	-------	2.286 S	100–1,493 S	.711/S^2	1,417	66.6	.0266	840	56.6	.0345
	.40 S	-------	2.963 S	100–1,781 S	.533/S^2	1,062	60.1	.0307	629	48.2	.0399
	.50 S	-------	3.559 S	100–2,030 S	.427/S^2	851	54.5	.0343	504	40.9	.0445
	.60 S	-------	4.100 S	100–2,250 S	.355/S^2	708	49.6	.0376	419	34.5	.0488
	.70 S	-------	4.596 S	100–2,448 S	.305/S^2	608	45.2	.0406	360	28.8	.0527
	.80 S	-------	5.059 S	100–2,630 S	.267/S^2	532	41.1	.0434	315	23.5	.0563
	.90 S	-------	5.494 S	100–2,797 S	.237/S^2	472	37.4	.0460	280	18.6	.0597
	1.00 S	-------	5.905 S	100–2,953 S	.213/S^2	425	33.9	.0485	251	14.1	.0631
Case III	1.10 S	0.10 S	6.306 S	100–3,103 S	.193/S^2	385	30.5	.0510	228	9.7	.0662
	1.20 S	.20 S	6.705 S	100–3,253 S	.176/S^2	351	27.2	.0534	208	5.3	.0694
	1.30 S	.30 S	7.103 S	100–3,402 S	.161/S^2	321	23.8	.0558	190	1.0	.0725
	1.40 S	.60 S	8.293 S	100–3,846 S	.127/S^2	253	13.8	.0629	150	−12.0	.0817

For Case I corresponding values of Bn and $_{150}Rc$ are calculated by use of the formula $Bn=\frac{1,492.9}{S(100-{}_{150}Rc)}$.

A circle was then drawn for each tracing, fitting as closely as possible the curved portion. The lines bounding the conical portion were extended to determine the point D. (See fig. 3.) Values of CD and r could then be determined. These data are found in Table 7.

The extent to which the experimental Brinell and Rockwell numbers obtained in this investigation may have been influenced by peculiar characteristics of the particular machines used is not known.

No attempt was made to find and interpret any systematic differences in the experimental values for steels which might result from different treatments. A. Heller [6] has shown that depth of hardening is a very important factor to be considered in deriving conversion formulas for steels.

[6] American Machinist, Apr. 4, 1929.

TABLE 7.—*Data on Rockwell diamond brales*

Manufacturer's No.	Position [1]	Angle of cone	r [2]	CD	S calculated from r	S calculated from CD
		° ′	*mm*	*mm*	*mm*	*mm*
26–1886	1	120 0	0.200	0.0336	0.0268	0.0291
	2	120 6	.180	.0293	.0241	.0254
	3	120 18	.192	.0315	.0257	.0273
26–1832	1	119 55	.182	.0271	.0244	.0235
	2	119 51	.167	.0271	.0224	.0235
	3	120 3	.199	.0326	.0267	.0282
26–15	1	120 1	.202	.0315	.0271	.0273
	2	120 1	.191	.0315	.0256	.0273
	3	120 18	.201	.0326	.0269	.0282
29–1893	1	119 41	.212	.0336	.0284	.0291
	2	119 32	.200	.0326	.0268	.0282
	3	119 53	.197	.0315	.0264	.0273
26–224	1	120 25	.205	.0326	.0275	.0282
	2	120 4	.198	.0315	.0265	.0273
	3	119 48	.197	.0315	.0264	.0273

[1] The brale was turned into position 2 from position 1 by rotating it 60° about its axis. An additional 60° rotation brought it into position 3.
[2] The meaning of the notation used in this table is given in fig. 3.

VII. CORRELATION OF APPROXIMATE THEORY AND EXPERIMENT

When one plots the first three equations of Table 1 using values of R_B and $\frac{1}{Bn}$ as coordinates, straight lines are obtained. Likewise, the second three equations give straight lines if values of R_c and $\frac{1}{\sqrt{Bn}}$ are used as coordinates. Graphs of the first, second, and fourth of these equations are shown by dash lines in Figures 4 and 5.

The curve forming the upper boundary of the shaded area in Figure 5 was plotted from data found in columns 7 and 8, Table 6, and the curve forming the lower boundary was plotted from values found in columns 10 and 11.

The upper curve gives the theoretical relationship between Bn and ${}_{150}R_C$ for a brale in which $S=0.0224$ mm, and the lower curve does the same for a brale in which $S=0.0291$ mm. These particular values of S were chosen merely because they were the minimum and maximum values found in the study of the five tools and may represent an extreme variation in S. Average values would show less variation.

Certain facts are made evident by an inspection of the theoretical straight line curve (for a true cone) and the theoretical curves bounding the shaded areas.

The effect of the spherical portion of the brale upon the theoretical relationship between Bn and ${}_{150}R_C$ is quite small for ${}_{150}R_C=10$, but gradually increases and becomes quite large at ${}_{150}R_C=70$.

If two brales are used having different values of S, the effect of this difference in S is quite small for ${}_{150}R_C=10$, but becomes considerably larger at ${}_{150}R_C=70$.

Thus the theoretical value of Bn corresponding to ${}_{150}R_C=70$ is 1,678 for $S=0.0224$ mm and only 1,460 for $S=0.0291$ mm.

Experimental values taken from Tables 3 and 4 are plotted in Figures 4 and 5. Considering Figure 4, we see that the points do not fall along the theoretical straight lines, but that their mean

positions are determined fairly well by the two full lines. Since these are straight lines, equations of the form $Bn=\frac{C}{(130-R_B)}$ can be used as conversion formulas. The numerical values to be substituted for C are the reciprocal slopes of the experimental curves. Thus, the

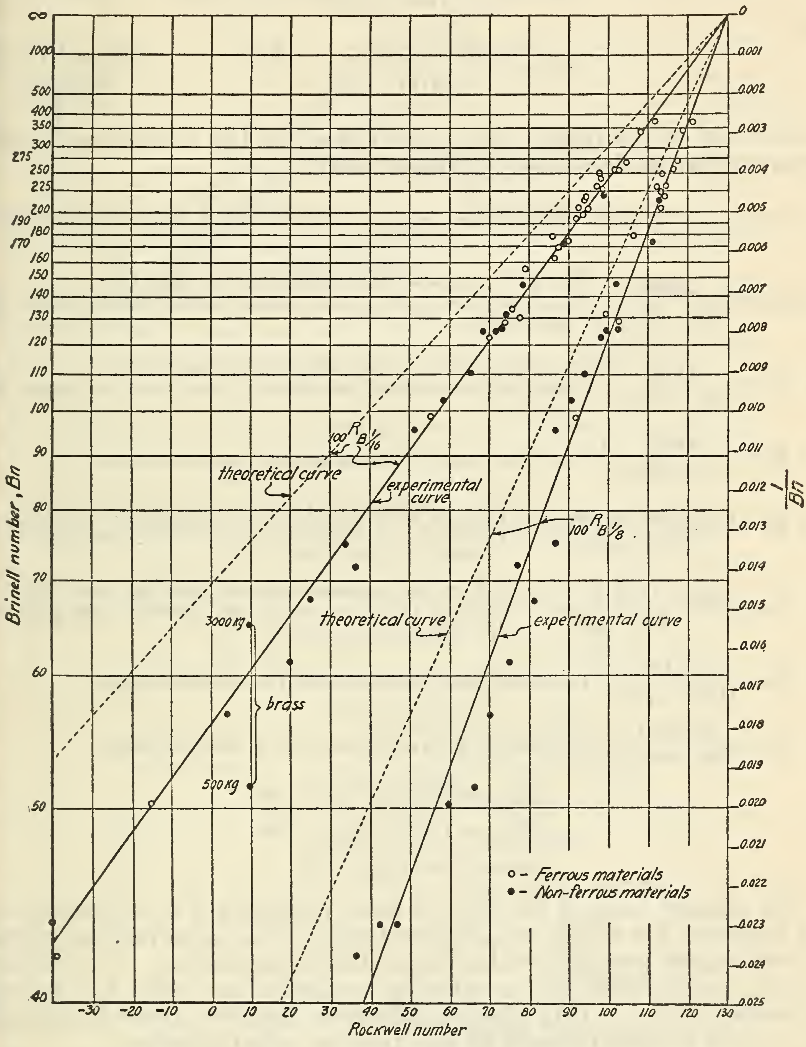

Figure 4.—*Relation of Brinell numbers to Rockwell ball numbers*

reciprocal slope of the ${}_{100}R_{B1/16}$ line is $\frac{146}{0.020}=7{,}300$, and the equation is:

$$Bn=\frac{7{,}300}{(130-{}_{100}R_{B1/16})}$$

Equations (*a*), (*b*), and (*c*) of Table 8 were obtained in this way.

The experimental points plotted in Figure 5 determine a curve which is displaced from the theoretical curves. As would be expected,

its general form is like that of the theoretical curves for a brale with a spherical apex.

This curve was used to determine the empirical equations:

$$Bn=\frac{1{,}520{,}000-4{,}500\ {}_{150}R_C}{(100-{}_{150}R_C)^2}$$

and

$$Bn=\frac{25{,}000-10\,(57-{}_{150}R_C)^2}{100-{}_{150}R_C} \qquad (d) \text{ and } (e) \text{ of Table 8}$$

which hold in the ranges ${}_{150}R_C$ greater than 10, less than 40 and ${}_{150}R_C$ greater than 40, less than 70, respectively.

TABLE 8.—*Empirical relationships between Rockwell and Brinell indentation numbers*

(a) $Bn=\dfrac{7{,}300}{130-{}_{100}R_{B1/16}}$	For ${}_{100}R_{B1/16}$ greater than 40 and less than 100. Error to be expected not greater than plus or minus 10 per cent.
(b) $Bn=\dfrac{3{,}710}{130-{}_{100}R_{B1/8}}$	For ${}_{100}R_{B1/8}$ greater than 30 and less than 100. Error to be expected not greater than plus or minus 10 per cent.
(c) $Bn=\dfrac{4{,}030}{130-{}_{60}R_{B1/16}}$	This load is not recommended by manufacturer.
(d) $Bn=\dfrac{1{,}520{,}000-4{,}500\ {}_{150}R_C}{(100-{}_{150}R_C)^2}$	For ${}_{150}R_C$ greater than 10 and less than 40. Error to be expected not greater than plus or minus 10 per cent.
(e) $Bn=\dfrac{25{,}000-10\ (57-{}_{150}R_C)^2}{100-{}_{150}R_C}$	For ${}_{150}R_C$ greater than 40 and less than 70. Error to be expected not greater than plus or minus 10 per cent.
(f) $Bn=\dfrac{768{,}000}{(100-{}_{100}R_C)^2}$	This load is not recommended by manufacturer.
(g) $Bn=\dfrac{333{,}000}{(100-{}_{60}R_C)^2}$	This load is not recommended by manufacturer.

$${}_{100}R_{B1/16}=1.97\times{}_{100}R_{B1/8}-126$$

$${}_{100}R_{B1/16}=1.81\times{}_{60}R_{B1/16}-105$$

$${}_{100}R_C=1.518\times{}_{60}R_C-51.8$$

The general form of the first of these equations was suggested by the fact that for values of ${}_{150}R_C$ less than 40 the experimental curve is very nearly parallel to the theoretical straight line. For values of ${}_{150}R_C$ greater than 40 the spherical portion of the brale has a very noticeable effect. This was an indication that the general form of the second equation should be like that for a ball indenter.

Equations (*f*) and (*g*) of Table 8 were obtained by following the procedure used in getting equations (*a*), (*b*), and (*c*). In place of each of these equations we should very likely have two equations similar in form to (*d*) and (*e*). There was not sufficient data available for checking this point.

The last three equations of Table 8 were obtained by equating values of Bn taken from this same table. These equations differ very little from the corresponding theoretical equations of Table 1. A graphical comparison of two cases is made in Figure 6,

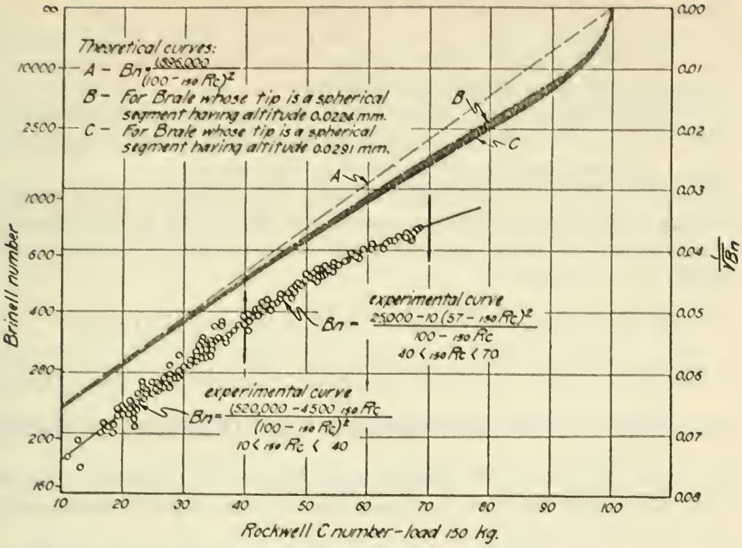

FIGURE 5.—*Relation of Brinell numbers to Rockwell cone numbers*

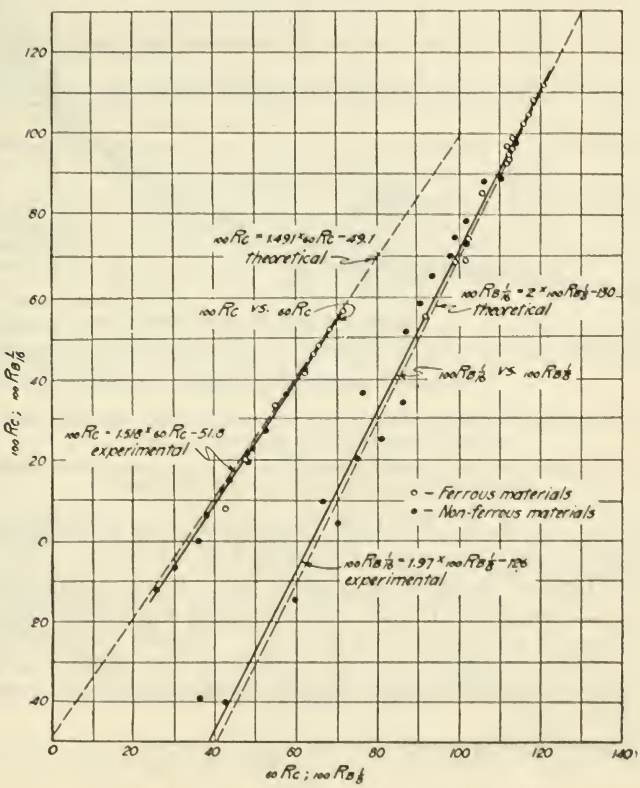

FIGURE 6.—*Comparison of Rockwell numbers*

A comparison of Tables 1 and 8 shows that in every case:
(Bn) theor $\times(130-R_B)$ theor $>(Bn)$ expt $\times(130-R_B)$ expt and (Bn) theor $\times(100-R_C)^2$ theor $>(Bn)$ expt $\times(100-R_C)^2$ expt. The explanation for this is in part as follows:

1. The flattening of the Brinell ball due to compression probably results in an area of indentation larger than one would obtain with a rigid ball. Consequently (Bn) theor $>(Bn)$ expt.

2. Elastic recovery of the material and deformation of the indenting tool due to compression tend to make the Rockwell indentation shallower than it would be if the material were perfectly plastic and the tool rigid. As a result:

$$(R_B) \text{ theor} < (R_B) \text{ expt and } (R_C) \text{ theor} < (R_C) \text{ expt}$$

or

$$(130-R_B) \text{ theor} > (130-R_B) \text{ expt and } (100-R_C) \text{ theor} > (100-R_C) \text{ expt.}$$

VIII. ACCURACY OF EMPIRICAL CONVERSION FORMULAS

The range of values of Brinell and Rockwell numbers (standard loads and standard tools) for which each of the experimental conver-

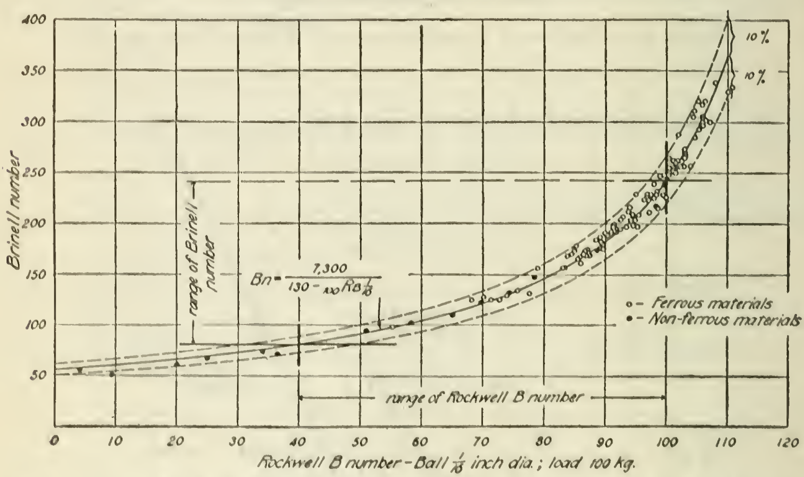

FIGURE 7.—*Experimental relationship between Brinell numbers and Rockwell ball numbers, ball diameter 1/16 inch*

The ranges indicated are those over which the empirical conversion curve may be applied with the expectation of no error greater than 10 per cent.

sion formulas can be used and the maximum error to be expected can be obtained by an inspection of Figures 7, 8, and 9.

In these figures broken-line curves have been drawn above and below the curves plotted from the empirical equations and marked plus 10 per cent and minus 10 per cent. Values of Brinell number used in plotting these curves were obtained by adding to and subtracting from Brinell numbers read from the empirical curves 10 per cent of their value.

As indicated in Figure 7, the formula

$$Bn = \frac{7{,}300}{(130 - {}_{100}R_{B1/16})}$$

can be used for the range of Rockwell B number (ball 1/16 inch diameter; load 100 kg) from 40 to 100 or of Brinell number from 80 to 240. All of the experimental points in this range fall within the 10 per cent limits. The upper end of the range is set at ${}_{100}R_{B1/16}=100$, even though there seems to be good agreement between theory and experiment for larger values of ${}_{100}R_{B1/16}$. This is done because the

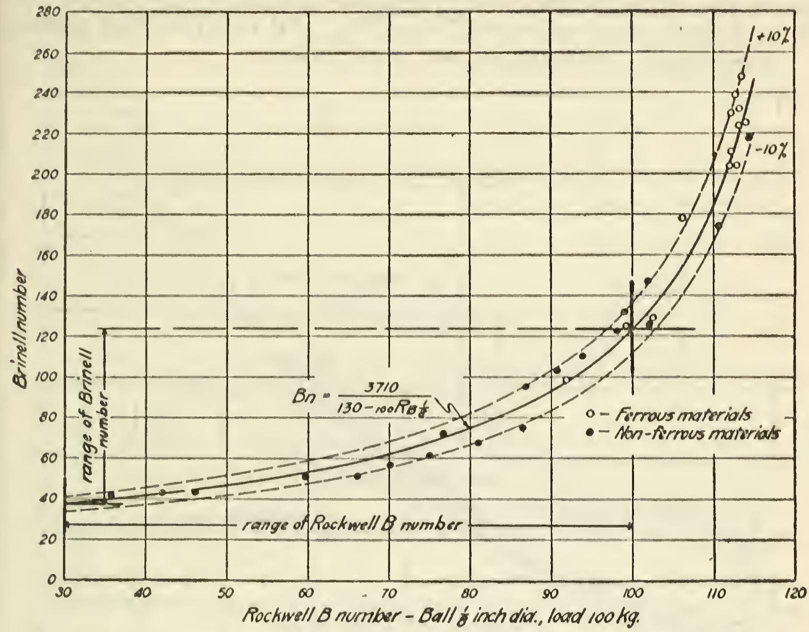

FIGURE 8.—*Experimental relationship between Brinell numbers and Rockwell ball numbers, ball diameter 1/8 inch*

The ranges indicated are those over which the empirical conversion curve may be applied with the expectation of no error greater than 10 per cent.

relative effect of an error in ${}_{100}R_{B1/16}$—that is, the ratio of the error to $(130-{}_{100}R_{B1/16})$—is very large when ${}_{100}R_{B1/16}$ is greater than 100.

As shown in Figure 8 the formula

$$Bn=\frac{3{,}710}{130-{}_{100}R_{B1/8}}$$

holds about equally well throughout the range of Rockwell B number (ball 1/8 inch diameter; load 100 kg) from 30 to 100 or of Brinell number from 40 to 125. The check on the accuracy of this formula is not conclusive because of insufficient data.

As shown in Figure 9, the formula

$$Bn=\frac{1{,}520{,}000-4{,}500\times{}_{150}R_C}{(100-{}_{150}R_C)^2}$$

holds for the range of Rockwell C number (load 150 kg) from 10 to

40 or of Brinell number from 180 to 370. Ninety-five per cent of the experimental points fall within the 10 per cent limits.

Likewise, the formula

$$Bn = \frac{25{,}000 - 10\ (57 - {}_{150}R_C)^2}{100 - {}_{150}R_C}$$

holds for the range of Rockwell C number (load 150 kg) from 40 to 70 or of Brinell number from 370 to 770. All experimental points in this range fall within the 10 per cent limits.

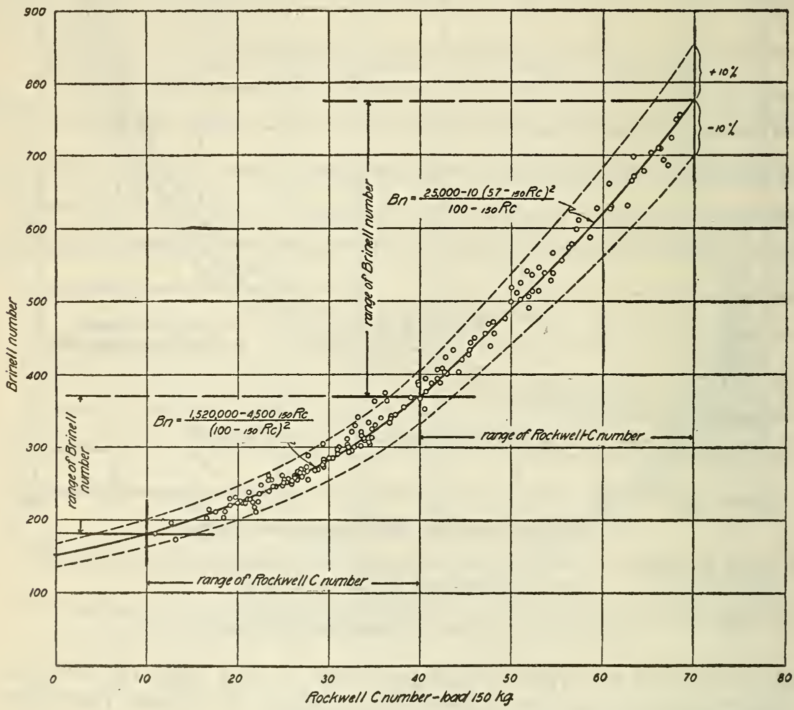

FIGURE 9.—*Experimental relationship between Brinell numbers and Rockwell cone numbers*

The ranges indicated are those over which the empirical conversion curve may be applied with the expectation of no error greater than 10 per cent.

IX. RELATIONSHIP OF ROCKWELL NUMBERS TO TENSILE STRENGTH

Earlier investigators [7] have established the fact that a rough proportionality exists between the tensile strength of steel and its Brinell number.

The equations sometimes used in calculating the tensile strength of steel [8] are:

Tensile strength (lbs./in.^{2}) = 515 Bn for Brinell numbers less than 175.

Tensile strength (lbs./in.^{2}) = 490 Bn for Brinell numbers greater than 175.

[7] Die Brinellsche Kugeldruckprobe, P. W. Döhmer, Berlin; 1925.
[8] See Die Brinellsche Kugeldruckprobe, P. W. Döhmer, Berlin, p. 48; 1925.

Since an empirical relationship between Bn and ${}_{100}R_{B1/16}$ has been found (see Table 8) the above equations can be transformed to read:

$$\text{Tensile strength (lbs./in.}^2\text{)} = \frac{3,760,000}{130 - {}_{100}R_{B1/16}} \text{ for } {}_{100}R_{B1/16} \text{ less than 88.}$$

$$\text{Tensile strength (lbs./in.}^2\text{)} = \frac{3,580,000}{130 - {}_{100}R_{B1/16}} \text{ for } {}_{100}R_{B1/16} \text{ greater than 88.}$$

The dash lines in Figure 10 are the graphs of these equations.

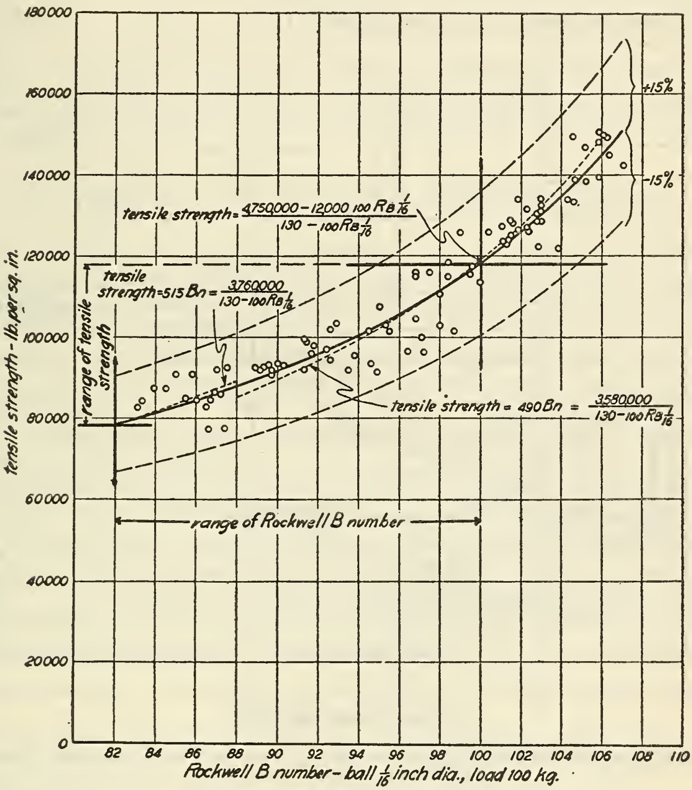

Figure 10.—*Experimental relationship between the tensile strength of steel and Rockwell ball number, ball diameter 1/16 inch*

The ranges indicated are those over which the empirical conversion curve may be applied with the expectation of no error greater than 15 per cent.

The full line curve in Figure 10 is the graph of the empirical equation:

$$\text{Tensile strength (lbs./in.}^2\text{)} = \frac{4,750,000 - 12,000 \times {}_{100}R_{B1/16}}{130 - {}_{100}R_{B1/16}}$$

the general form of which was suggested by the last two equations given above. None of the experimental tensile strengths differ from corresponding values obtained from this curve by more than 15 per cent. It is suggested that this equation be used over the range of

Rockwell B number (ball $\frac{1}{16}$ inch diameter; load 100 kg) from 82 to 100 or of tensile strength from 80,000 to 120,000 lbs./in.^{2}.

If values of Bn in terms of ${}_{150}R_C$ (see equations (d) and (e), Table 8) be multiplied by 490 the following expressions are obtained:

$$\text{Tensile strength (lbs./in.}^2) = \frac{10^5(7{,}450 - 22 \times {}_{150}R_C)}{(100 - {}_{150}R_C)^2} \text{ for } {}_{150}R_C \text{ less than 40.}$$

$$\text{Tensile strength (lbs./in.}^2) = \frac{490(25{,}000 - 10(57 - {}_{150}R_C)^2)}{100 - {}_{150}R_C} \text{ for } {}_{150}R_C$$

greater than 40.

These equations are plotted in Figure 11.

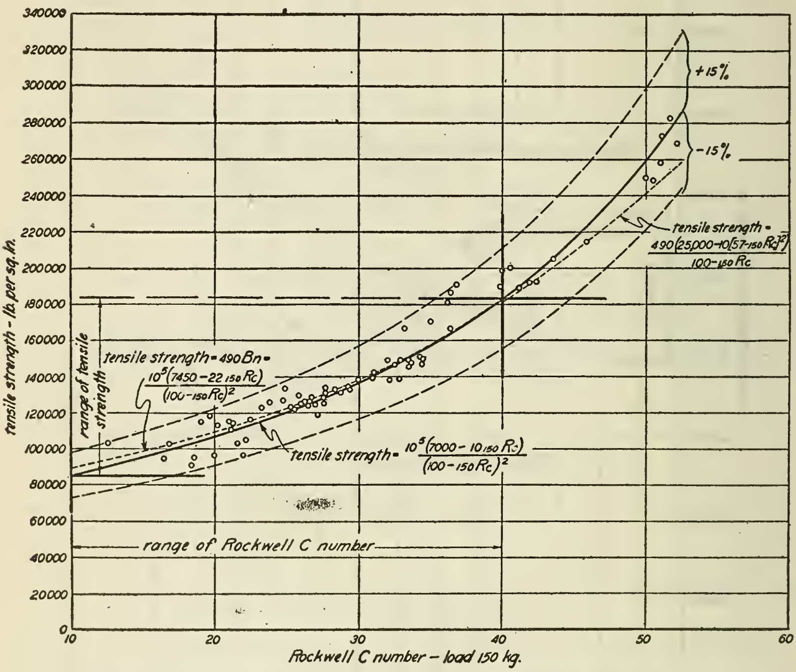

FIGURE 11.—*Experimental relationship between the tensile strength of steel and Rockwell cone number*

The ranges indicated are those over which the empirical conversion curve may be applied with the expectation of no error greater than 15 per cent.

The full line curve in this Figure 11, which seems to satisfy the experimental data better than the dash line curves, especially in the range above ${}_{150}R_C = 40$, is a graph of the empirical equation:

$$\text{Tensile strength (lbs./in.}^2) = \frac{10^5(7{,}000 - 10 \times {}_{150}R_C)}{(100 - {}_{150}R_C)^2}.$$

None of the experimental values differ by more than 15 per cent from corresponding values read from the full line conversion curve. This

accuracy is about the same as that holding in a conversion from Brinell number to tensile strength.[9]

It is suggested that this curve be used only over the range of Rockwell C number (load 150 kg) from 10 to 40 or of tensile strength from 90,000 to 190,000 lbs./in.^{2}. The experimental check on the curve in the range above $_{150}R_C=40$ is not sufficient to warrant using it as a conversion curve. With the exception of the two aluminum alloys (Nos. 11 and 12), which fall in line with the ferrous alloys, the nonferrous alloys showed no definite relationships between tensile strengths and Rockwell numbers. This was to be expected in view of the failure of previous investigators to find definite relationships for nonferrous metals (with the exception of aluminum alloys) between tensile strengths and Brinell numbers. The recent work of Schwarz [10] indicates that no general relationship between tensile strength and a single indentation number is possible, the approximate proportionality existing for steel and duralumin being the result of their relatively high elastic ratio.

X. RESULTS OF EARLIER INVESTIGATORS

The desirability of having some means for comparison of the Rockwell and the Brinell numbers was recognized with the increased use of the Rockwell machine. During the last few years several investigations have been made for the purpose of obtaining the experimental relationships between the Rockwell and the Brinell numbers. The summary of these investigations and the principal results obtained are found below:

1. S. C. Spalding, Transactions of the American Society for Steel Treating, October, 1924.

The experiments were made on steels having a tungsten content of about 17 per cent and drawn at different temperatures. The results showed that within the range Bn greater than 300 and less than 650 the Brinell number is linearly related to the Rockwell cone number. No conversion formula was recommended, but the relationship between the Rockwell cone number and the Brinell number may be roughly expressed by the equation

$$Bn=12.5\,{}_{150}R_C-137$$

2. I. H. Cowdrey, Transactions of the American Society for Steel Treating, February, 1925.

Many ferrous and nonferrous materials were tested, including overstrained, cold-worked, and heat-treated material. The following equations were derived:

$$Bn=\frac{{}_{100}R_{B1/16}+273}{6.49-0.048\times{}_{100}R_{B1/16}}$$

and

$$Bn=\left\{\frac{{}_{150}R_C+192}{88.3}\right\}^{6.21}$$

[9] See Relation Between Maximum Strength, Brinell Hardness, and Scleroscope Hardness in Treated and Untreated Alloy and Plain Steels, by R. A. Abbot, Proc. Am. Soc. Test. Mat., 15; 1915.

[10] Otto Schwarz, Zugfestigkeit und Härte bei Metallen, Forschungsarbeiten auf dem gebiete des Ingenieurwesens, Heft 313; 1929.

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3. R. C. Brumfield, Transactions of the American Society for Steel Treating, June, 1926.

These tests also included nonferrous materials and steels treated in various ways. The following equations were derived:

$$Bn = \frac{6{,}600}{127 - {}_{100}R_{B1/16}}$$

and

$$Bn = \frac{1{,}880{,}000}{(112 - {}_{150}R_C)^2}$$

The results obtained in these investigations are plotted in Figures 12 and 13. In Figure 12 the Brinell and the Rockwell numbers are

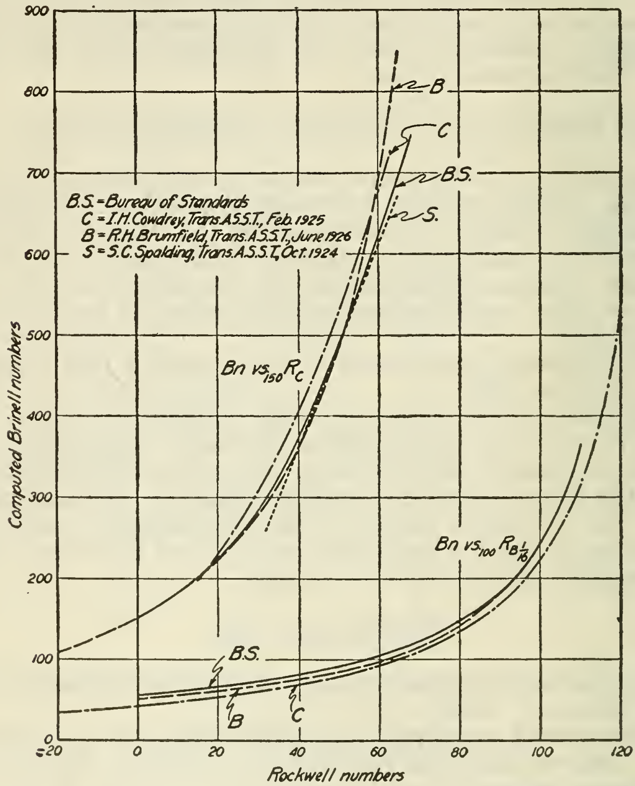

FIGURE 12.—*Relationships between Brinell and Rockwell numbers given by different investigators*

plotted using uniform scales, so that a ready comparison of the Brinell numbers computed from the Rockwell numbers can be made. In Figure 13 the Rockwell numbers are plotted: ${}_{100}R_{B1/16}$ against $\frac{1}{Bn}$, and ${}_{150}R_C$ against $\frac{1}{\sqrt{Bn}}$, as was done in Figures 4 and 5. In this way the differences between the various equations are brought out more clearly.

It will be noted that Brumfield's equations are of the same type as the equations given in this paper. The agreement between the two groups of equations is fairly good, except for the upper range of the Rockwell cone number.

XI. SUMMARY

The tensile strengths and the Brinell and Rockwell indentation numbers were obtained for a variety of ferrous and nonferrous metals.

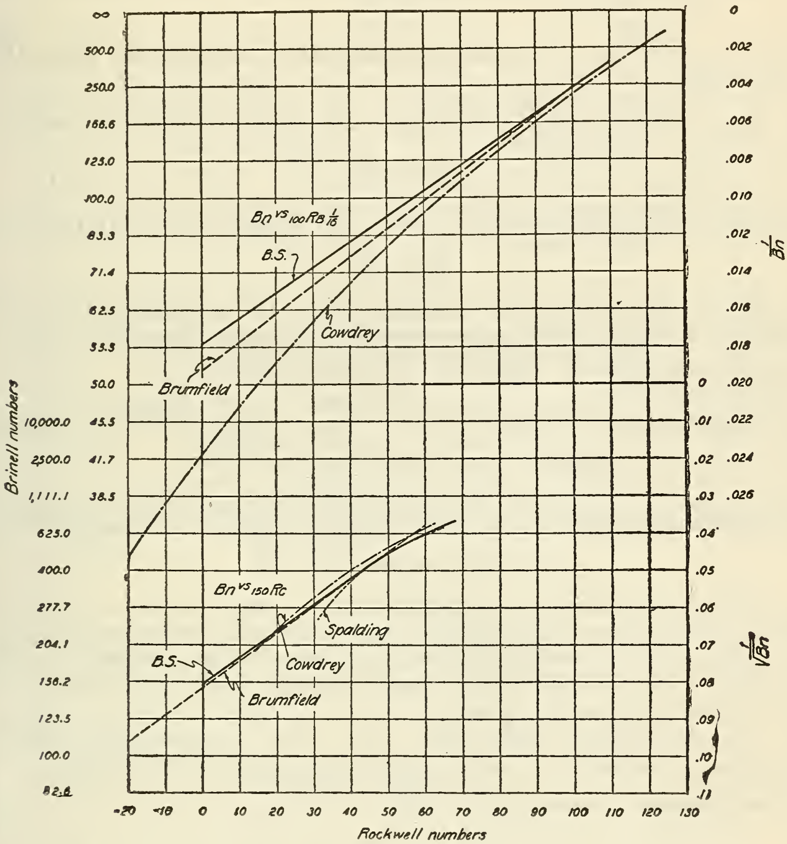

FIGURE 13.—*Relationships between Brinell and Rockwell numbers obtained by different investigators*

Rockwell number vs. $\frac{1}{\sqrt{Bn}}$ and $\frac{1}{Bn}$

1. The experimental indentation numbers made it possible to obtain semiempirical formulas for calculating Brinell numbers from Rockwell numbers, or vice versa. When used over the range specified each of these formulas gives values in which the error to be expected is not greater than plus or minus 10 per cent.

Using the following notation:

${}_{100}R_{B1/16}$; Rockwell B number, ball 1/16 inch diameter, load 100 kg.

${}_{100}R_{B1/8}$; Rockwell B number, ball 1/8 inch diameter, load 100 kg.

${}_{150}R_C$; Rockwell C number, brale, load 150 kg.

these equations are:

(*a*) $Bn = \dfrac{7{,}300}{130 - {}_{100}R_{B1/16}}$ for ${}_{100}R_{B1/16}$ greater than 40 and less than 100.

(*b*) $Bn = \dfrac{3{,}710}{130 - {}_{100}R_{B1/8}}$ for ${}_{100}R_{B1/8}$ greater than 30 and less than 100.

(*c*) $Bn = \dfrac{1{,}520{,}000 - 4{,}500\ {}_{150}R_C}{(100 - {}_{150}R_C)^2}$ for ${}_{150}R_C$ greater than 10 and less than 40.

(*d*) $Bn = \dfrac{25{,}000 - 10(57 - {}_{150}R_C)^2}{100 - {}_{150}R_C}$ for ${}_{150}R_C$ greater than 40 and less than 70.

2. For steels the tensile strength may be calculated from the Rockwell number, with expectation of an error less than plus or minus 15 per cent, by using the empirical formulas:

(*a*) Tensile strength (lbs./in.²) $= \dfrac{4{,}750{,}000 - 12{,}000\ {}_{100}R_{B1/16}}{130 - {}_{100}R_{B1/16}}$ for ${}_{100}R_{B1/16}$ greater than 82 and less than 100.

(*b*) Tensile strength (lbs./in.²) $= \dfrac{10^5(7{,}000 - 10 \times {}_{150}R_C)}{(100 - {}_{150}R_C)^2}$ for ${}_{150}R_C$ greater than 10 and less than 40.

3. The six equations given above have been plotted. On each graph additional curves are drawn, one above and one below the given conversion curve, showing the maximum error to be expected in using the curve. The recommended range of application of each conversion curve is indicated on the graph.

4. No discernible relationship was found between the tensile strengths of nonferrous metals and their indentation numbers.

WASHINGTON, December 29, 1929.